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0215581.0

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UNIVERSITY OF BRISTOL
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Tyndall Avenue
BRISTOL
BS8 1TH

7981001

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation — UNITED KINGDOM

4. Title of the invention — SCANNING PROBE MICROSCOPE

5. Name of your agent *(if you have one)* — STEVENS HEWLETT & PERKINS

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Halton House
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EC1N 2JD

Patents ADP number *(if you know it)* — 1545003

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Description	15
Claim *(s)*	4
Abstract	
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
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11. I/We request the grant of a patent on the basis of this application.

Signature C. Williams Date 04/07/2002

Agents for the Applicant

12. Name and daytime telephone number of person to contact in the United Kingdom: Dr CEILI WILLIAMS; 020 7404 1955

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SCANNING PROBE MICROSCOPE

This invention relates to the field of scanning probe microscopes and to a method of scanning such microscopes.

The field of scanning probe microscopy began in 1981 with the development of the scanning tunnelling microscope. Since that date a vast range of further probe microscopes have been developed, although they are all based on the same fundamental operational principle: a nanometric probe is mechanically scanned over a sample surface in order to acquire an "interaction map" of the sample space. Each different type of scanning probe microscope (SPM) is characterised by the nature of the local probe and its interaction with the sample surface.

Some probe techniques, scanning near field optical microscopy (SNOM) and photon scanning tunnelling microscopy (PSTM), detect photons generated as a result of probe interaction with an illuminated sample. Others are based on the detection of variations in a probe – sample interaction force. Techniques in this latter group are known generically as scanning force microscopy (SFM). The interaction force may be, for example, magnetic, capacitive, shear force or thermal, among many others.

Atomic force microscopy (AFM) is the most commonly used scanning probe microscopy technique. The probe in this case is a tip on the end of a cantilever which bends in response to the force between the tip and the sample. An optical lever technique is used to measure the bending of the cantilever. Since the cantilever obeys Hooke's Law for small displacements, the interaction force between the tip and the sample can be deduced. The AFM is commonly operated in one of two modes. In constant force mode, feedback enables a positioning piezoelectric driver to move the sample (or tip) up or down in response to any change in the

interaction force which is detected. In this way, the interaction force may be held relatively steady and a fairly faithful topographical image of the sample is obtained. Alternatively the AFM may be operated in constant height mode. Topographical changes are then indistinguishable from interaction force variations and so this mode of operation is most useful for imaging very flat samples at high resolution.

A disadvantage of all scanning probe microscopy techniques is data collection time. Typically, the image is made up of 256 lines, each line consisting of 256 points (pixels). A full image scan taken with the necessarily small probe is time consuming. Local probe techniques are increasingly being used to read and write data beyond the $\lambda/2$ limitation of conventional optical storage media and it is rapidly becoming apparent that the speed of data processing is limited by the speed with which information can be read. Moreover many scientific, industrial and physiological processes occur on too short a timescale to allow them to be followed using local probe techniques. There is therefore a perceived need to improve image collection times in scanning probe microscopy.

It is an object of this invention to provide a system capable of more rapid collection of sample – probe interactions and thereby to increase information readout rates and to open up more scientific, industrial and physiological processes to real-time investigation by scanning probe microscopy.

The present invention provides a scanning force microscope for imaging a sample in accordance with an interaction force between the sample and a probe, the microscope comprising driving means arranged to provide relative motion between the probe and the sample surface and capable of bringing the sample and probe into close proximity, sufficient for a detectable interaction force to be established between them; means for oscillating the probe across the surface; a probe detection mechanism

arranged to measure at least one parameter indicative of the strength of the interaction force between the probe and the sample; and a feedback mechanism arranged to provide for adjustment of probe – sample separation via operation of the driving means in response to a variation in an average value of one of the at least one parameters away from a predetermined set value; characterised in that, the microscope is arranged, in operation, to carry out a scan of the sample surface wherein scan area is covered by an arrangement of scan lines, each scan line being collected by oscillating the probe at or near its resonant frequency such that oscillation amplitude determines scan line length and their arrangement is provided by operation of the driving means.

In near- or at- resonant oscillation the probe will move very rapidly over the sample surface. Each scan line is collected as a continuous (analogue) image as the probe oscillates across the surface of the sample. By simultaneously providing relative motion between the probe and sample surface, successive scan lines will collect information from different parts of the surface. After covering an area of the surface, scan line information can be collected and reconstituted with appropriate displacements to form an image of the two-dimensional scan area. The feedback mechanism serves to maintain, to some degree, height of the probe above the surface by making adjustments in accordance with the average strength of the interaction force between probe and sample. Variations in the measured parameter within the timescale of an oscillation therefore constitute the "interaction" image, and are interpreted as arising from true surface features. This provides a far more rapid technique with which to collect interaction image information than is available in the prior art.

Various orientations of probe oscillation and probe / surface relative motion may be used to cover the scan area. A linear translation may be applied in a direction which is substantially orthogonal to a plane in which the probe is oscillated, thereby defining a substantially rectangular scan area. If the

relative motion is continuous, the scan area is rapidly covered by a single, continuous, zigzagging line. Alternatively, a circular arrangement may be generated by providing a relative rotation of probe and sample about an axis substantially coincident with that about which the probe is oscillated. Moreover, oscillation may also follow a figure of eight path, again with a rotational relative motion.

The probe is preferably metallic and the parameter indicative of the interaction force is capacitance of an interface between probe and sample. This technique is very useful in mapping charge distributions within semiconductor materials. The improved scanning speed facilitated by the present invention opens up internal semiconductor processes to real-time investigation by probe microscopy.

Alternatively, the parameter indicative of the interaction force is oscillation amplitude. Oscillation amplitude may also be the monitored parameter on which the feedback mechanism is based.

The probe detection mechanism preferably comprises a modulation signal generator arranged to apply a modulating voltage across the interface between probe and sample in order to modulate its characteristics and thereby affect its electrical capacitance, a resonator arranged to set up a resonating electric field in a circuit incorporating the probe and sample and a detector arranged to measure the electric field resonant frequency and thereby to enable variations in the capacitance of the interface to be measured as the modulating voltage is applied. The advantage of this embodiment of the invention is that it provides an extremely sensitive technique with which to measure capacitance in a scanning capacitance microscope.

Alternatively, the probe may comprise a cantilever and actuator arranged to drive the cantilever in a "tapping" mode and the parameter indicative of the

strength of the interaction force is bending of the cantilever as it taps the sample. This provides an implementation of the invention in an atomic force microscope, and opens up to faster scanning the applications to which the AFM is generally put.

As a further alternative the microscope may be a magnetic force microscope with the probe adapted to interact with a magnetic field and the probe detection mechanism arranged to measure a parameter indicative of the magnetic interaction between the probe and the sample.

The feedback mechanism preferably operates with a time constant which is greater than one cycle of probe oscillation and significantly less than total time taken to perform a scan.

In a second aspect, the present invention provides a method of rapidly collecting image data from a scan area of a sample with nanometric features wherein the method comprises the steps of:-

(a) Moving a probe with tip of sub-nanometric dimensions into close proximity with a sample in order to allow an interaction force to be established between probe and sample;

(b) Oscillating the probe across the surface of the sample at or near its resonant frequency whilst providing a relative motion between the probe and surface such that an arrangement of scan lines, whose length corresponds to oscillation amplitude, covers the scan area;

(c) Measuring a parameter indicative of the interaction force strength;

(d) Monitoring the parameter measured in step (c) or a second parameter which is also indicative of an interaction force between probe and sample and, if a value of the monitored parameter falls below or rises above a predetermined set value, adjusting probe – sample separation

distance in order to drive the value of the monitored parameter back towards the set value; and

(e) Processing measurements taken at step (c) in order to extract information relating to the nanometric structure of the sample.

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings.

Figure 1 shows a schematic implementation of the invention in a scanning capacitance microscope.

Figure 2 shows schematically a probe detection mechanism suitable for use in the microscope of Figure 1.

Figure 1 illustrates a scanning capacitance microscope (SCM) implementation of the invention. A prior art SCM is described in T. Tran *et al.* ""Zeptofarad" (10^{-21}) resolution capacitance sensor for scanning capacitance microscopy", Rev. Sci. Inst. 72(6) p 2618 (2001) and has proved particularly useful in measuring two-dimensional carrier profiles of semiconductor devices. Like the microscope described by Tran *et al.*, the apparatus 10 shown in Figure 1 comprises an electrically grounded plate 14, adapted to receive a sample 12, which is connected to a piezoelectric transducer 16 and a coarse driving means 18. A metallic probe 20 is connected to a second piezoelectric driving means 22 which, unlike any prior art SCM driving means, is arranged to drive a near-resonance or resonant oscillation of the probe 20. Either the first 16 or second 22 piezoelectric transducer drives relative vertical motion of the probe 20 and sample 12. In this embodiment, it is the piezo 16 attached to the sample 12. The apparatus includes a probe detection mechanism 24, the particular details of which depend on the indicator of the probe 20 – sample 12 interaction force that is to be measured, and an embodiment suitable for

use with the SCM will be described in more detail later. A feedback mechanism 26 is arranged to drive the first piezo 16 in response to a signal received from the probe detection mechanism 24 and thus to control relative height of the probe 20 and sample 12. Collected data is analysed and output to a display 28.

As is conventional in the field, the *z* axis of a Cartesian coordinate system will be taken to be that perpendicular to a plane occupied by the sample 12. That is, the probe 20 – sample 12 interaction force is dependent both on the *xy* position of the probe 20 over the sample 12 (the pixel it is imaging), and also of its height above it.

Before considering the operation of the apparatus shown in Figure 1 it is helpful to explain the physics behind the interaction and measurements and hence the function of the probe detection mechanism 24. The scanning capacitance microscope may be used to image a number of sample types, including biological specimens. The generation and measurement of capacitance however is most readily understood in relation to semiconductor imaging. When a metal probe is brought into contact with a semiconductor material equalisation of the Fermi energy within the two band structures results in an electrical potential drop being developed across the boundary. This drop sweeps charge carriers out of the boundary region and a depletion layer is formed. This phenomenon is well known and is the basis behind the Schottky barrier diode. It is the capacitance across this depletion layer (or Schottky barrier) that is measured in semiconductors by SCM.

The band structure (and hence effective doping) of biological materials is markedly more complex than that of semiconductors, and the depletion layer theory outlined above is not in general appropriate. It is thought that a reorientation (or induction) of dipoles might be a mechanism in biological specimens which gives rise to a capacitance at the interface. Regardless

of the actual mechanism however, the fact remains that a capacitance is developed at the probe – sample interface and this can be detected and measured, in the same way as for semiconductor materials, by the scanning capacitance microscope.

The probe detection mechanism 24 for use in an SCM embodiment of this invention is shown in Figure 2. The mechanism 24 comprises a voltage-controlled oscillator 40, a coupled transmission line resonator 42, an amplifier 44, a peak detector 46 and a modulation signal generator 48. The modulation signal generator 48 applies a dc-biased ac sinusoidal voltage to the probe 20. The sample 12 itself is grounded via the plate 14 and so this effectively applies a modulating voltage across the interface between probe 20 and sample 12. This voltage modulates the depletion layer width in semiconductors and hence the capacitance of the barrier. In biological samples, the modulating voltage has a similar modulating effect on the capacitance, although probably through modulation of the dielectric constant. In order to measure interface capacitance, an oscillating electric field is excited in the resonator 48 circuitry by the oscillator 40. The resonance frequency of this field is dependent on the load (in this case an electrical path through probe and sample) on the circuit. The resonant signal is detected within the resonator 48 and amplified by the amplifier 44 before being passed to a peak detector 46. Variations in the capacitance at the interface (and hence load on the circuit) are reflected in a shift in frequency of the resonance peak, as detected by the peak detector 46. Since the modulation signal causing the capacitance fluctuations is known, determination of the variations in peak position enables the voltage derivative of the interface capacitance (dC/dV) to be determined at the modulation frequency.

Returning to Figure 1, in taking images using the apparatus 10, the sample 12 is first brought into the proximity of the probe 20 using the coarse driving means 18. Fine height and initial start position adjustments are made with

the first 16 piezo driver whilst the probe detection mechanism 24 measures the capacitance arising from the probe 20 – sample 12 interaction. Once the measured capacitance reaches a desired level, a raster scan of the sample 12 surface is begun. In scanning the probe 20 over the sample 12, the first piezo 16 controls movement in a *y* (into the page in the viewpoint shown in Figure 1) direction. The second piezo 22 drives a near resonant oscillation of the probe 20 about the *z* axis in the *xz* (i.e. plane of the Figure) plane. Probe oscillation is with a relatively large amplitude, of the order of a few microns. During the course of a scan, readings are continually taken by the probe detection mechanism 24 of the capacitance developed between probe 20 and sample 12.

Successive scan lines are collected as the probe 20 oscillates. Each line will therefore have a length equal to the oscillation amplitude, this length corresponding to the width of the image. The length of the image is of course determined by the distance the sample 12 is translated in the *y* direction by the first piezo 16. Oscillation near resonance enables near-maximum scan width to be obtained for a given drive force. By this means data from the imaged area is collected at a far higher speed than that achieved by prior art scanning capacitance microscopes, or indeed any other scanning force microscopes. Maximum scan width can clearly be achieved in the SCM if the probe is oscillated at resonance.

The feedback mechanism 26 is arranged to keep the average capacitance (averaged over many periods of oscillation) of the probe 20 – sample 12 interaction approximately constant. The output of the peak detector 46 (Figure 2) is fed to the feedback mechanism for this purpose. If at any point in the scan therefore a reduced average capacitance is observed, this indicates that the probe 20 – sample 12 interaction has decreased and accordingly separation distance has increased. The feedback mechanism 26 is therefore arranged to drive the first piezo transducer 16 such that it moves the sample 12 and plate 14 towards the probe 20. Conversely, a

larger capacitance signal indicates a decrease in probe 20 – sample 12 separation and the sample 12 is then lowered.. In practice, the average capacitance will vary around its set value. This variation has a number of contributory factors: overshoot in height adjustment, the fact that the time constant of the feedback loop has to be greater than the period of oscillation of the probe and the finite length of time it takes the probe to adjust to a change in interaction (settle time). Any changes in capacitance on timescales less that the period of probe oscillation constitute the image.

It is also important that the time constant of the feedback loop, which must be longer than the period of probe oscillation, and the response time of the probe must be shorter than the time taken to complete the entire scan. Otherwise the probe would not have time to adjust if there is much change in probe – sample separation.

The output signal from the probe detection mechanism 24 (peak detector 46) is fed via the feedback mechanism 26 to a processor and display 28. In order to enable digital data processing, the collected scan line may be artificially pixellated by the processor.

In order to maximise speed of the scan, each scan line is collected per half-oscillation of the probe. Clearly a better image could be obtained by multiple oscillations on each line although stepping and stopping the piezo drivers 16, 22 in order to provide for multiple traverses of the same line would lead to probe ringing. This would also, clearly, reduce overall scan speed. The speed of the sample piezo transducer 16 however can be set to move the sample as low as around 1Å per oscillation cycle. With this speed it is possible therefore to perform something akin to integration by adding consecutive lines together so that each line in a processed image becomes the average of, say, five oscillation lines. The increase in signal to noise ratio gained by this "integration" may, in many circumstances, more than compensate for the loss in resolution.

Although this embodiment of the invention incorporates a piezo 16 which provides for linear motion in the *y* direction, clearly many other scan geometries can be used. The only requirement, when imaging an area, is that the combination of sample (or, equivalently probe) translation and probe oscillation covers the area to be imaged. Thus, the sample could be rotated while the probe is oscillated, thereby making up a scan comprising a circular series of scan lines passing through a central point. Alternatively, the probe could be set to oscillate in two perpendicular directions. If oscillations are then driven in both directions together a non-linear oscillation, such as a figure of eight, will result. If the axis of the figure of eight oscillation was then rotated, the probe movement would cover the scan area in a series of figures of eight passing through a central point.

SCM is very useful for determining carrier profiles within semiconductor devices. The amplitude of *dC/dV* (when calibrated) can be used to determine the local carrier concentration and its sign gives the type of carrier. The advantage of faster scanning provided by the present invention will enable the SCM technique to be, not least, used to monitor processes occurring within semiconductor devices in real time.

The use of a probe oscillating at resonance to image a sample surface using optical SPM techniques is described in applicant's copending patent application no PCT/GB02/00512. One example described therein monitors the oscillation amplitude of the probe in order to maintain height above the surface. As a metallic probe is brought into the vicinity of a sample, interactive forces are manifest in a number of different ways. As described above in relation to the embodiment of this invention illustrated in Figure 1 the development a capacitance results from an electrical interaction. Another interaction is the so-called "shear force" damping mechanism. If a vertically-mounted probe is oscillated horizontally, with respect to the sample surface, at a frequency close to its resonant frequency, surface – probe interactions will serve to damp the oscillation amplitude. The

damping mechanism, under ambient conditions, is generally thought to be due to a confined water layer on the sample surface, but other damping interactions are also feasible. As the surface is approached by the probe, damping increases and accordingly oscillation amplitude is reduced.

An alternative to the embodiment of the invention shown in Figure 1 is therefore to adapt the probe detection mechanism 24 both to monitor the oscillation amplitude of the probe as it collects the scan lines and to measure the contact capacitance using the resonator 42 and voltage modulator 48 as before. Probe oscillation amplitude can be monitored by a number of known means, for example by photovoltaic measurement of an oscillating shadow of the probe tip in a light beam. The relative separation between sample 12 and probe 20 is then maintained on the basis of feedback from the oscillation amplitude. If the average (over a number of scan lines) amplitude falls below a set value, the sample 12 must be moved away from the probe 20 and if it rises above this set value, sample 12 and probe 20 should be brought closer together. This embodiment of the invention makes a two-fold use of probe resonant oscillations: to collect a scan line and to maintain height above the sample. At the same time, a capacitance image is taken of the sample 12.

In this embodiment of the invention the probe is oscillated near-resonance rather than at resonance, which would maximise scan width. This is because there is a greater response by way of amplitude change to a shift in position of the resonance peak when just off resonance. As it is this change in amplitude which is to be measured in this embodiment in order to provide an indication of any variation in probe – sample interaction, oscillating near resonance effectively improves the signal to noise ratio.

In using two different parameters to measure the probe – sample interaction and to monitor their separation respectively, the interaction image will be an "absolute" image, rather than relative. That is, in this

embodiment of the SCM, the capacitance image is formed from absolute values. In the previous embodiment, in which the average capacitance measurement is used to control the separation, the capacitance image obtained is a map of variations from this average value.

The generalised probe detection mechanism 24 shown in Figure 1 may comprise a number of different measurement tools, depending on the specifics of the probe – sample interaction being imaged.

As an alternative to the set up described above, the local probe 20 may be a cantilever probe and the detection mechanism 24 is adapted to be suitable for use with AFM. A prior art atomic force microscope suitable for imaging biological samples is described in "A high-speed atomic force microscope for studying biological macromolecules" by Toshio Ando *et al.*, Proc. Nat. Acad. Sci. USA 98(22) p12 468 – 12 472 (2001) and this equipment may be adapted for use with a resonantly oscillating cantilever / actuator for image scanning. Significant (for application of this invention) differences between AFM and SCM are that the former uses a small cantilever with, generally integrated, actuator as probe and, at least for imaging sensitive biological specimens, the actuator drives the cantilever in a "tapping" motion at its resonant frequency. The cantilever therefore only contacts the surface for a very small fraction of its oscillation (tapping) period. This dramatically shortened contact time means that lateral forces on the sample are very much reduced and the probe is therefore less destructive as it is scanned over the sample surface. In this implementation of the invention, there are two resonant modes to be exploited. The tapping mode is driven near to or at the resonant frequency of the cantilever. On the other hand, scanning oscillations, in accordance with this invention, are driven at the resonant frequency of the cantilever / actuator assembly. As the assembly is more massive, this will ensure a slower oscillation frequency, thereby enabling a number of contact points to be sampled within each scan line.

In a second alternative the probe detection mechanism 24 may be adapted to monitor and measure resonant oscillation amplitude, as described above in relation to an embodiment of the SCM. Instead of extracting capacitance measurements as an indicator of probe – sample interaction forces, anharmonic components of the damped oscillation are analysed and reconstructed to provide an image. This implementation makes a three-fold use of resonant (or near resonant) probe oscillation: first to provide faster scanning than is known in prior art systems, secondly to provide the basis for measurement of the probe – sample interactions and thirdly to maintain the height.

A third alternative is again to control resonant oscillation amplitude via feedback, but in this embodiment the probe is tilted so that it is no longer normal to the surface. The tilted probe is oscillated at resonance to collect each scan line, and a second detection system is set up to detect motion of the probe perpendicular to the angle of tilt. In this way the image is formed from small deviations in probe motion, normal to the tilt, measured by the second detection system within each oscillation cycle, whilst height control is via the main oscillation.

A fourth alternative is to adapt both the probe 20 and detection mechanism 24 to detect variations in the probe interaction with a sample magnetic field. For this purpose the probe may be in the form of a conducting loop and the detection mechanism adapted to measure currents induced therein as the probe performs its resonant scan. Alternatively the detection mechanism may measure changes in the resistance of the conducting loop. This latter alternative makes use of giant magnetoresistance, similar to that developed in a hard disk head on a resonantly oscillating probe. A third possibility is to use a metal probe, eddy currents will then provide a force resisting harmonic oscillation of the probe and the resulting anharmonic components may be again be used to form an image.

As will be apparent to one skilled in the art, there are many more techniques available for extracting probe – sample interaction information and these may be combined with the execution of a fast, resonant raster scan of the sample surface, in accordance with the present invention.

CLAIMS

1. A scanning force microscope (10) for imaging a sample (12) in accordance with an interaction force between the sample (12) and a probe (20), the microscope (10) comprising

   driving means (16, 18, 22) arranged to provide relative motion between the probe (20) and the sample surface and capable of bringing the sample (12) and probe (20) into close proximity, sufficient for a detectable interaction force to be established between them;

   means (22) for oscillating the probe (20) across the surface;

   a probe detection mechanism (24) arranged to measure at least one parameter indicative of the strength of the interaction force between the probe (20) and the sample (12); and

   a feedback mechanism (26) arranged to provide for adjustment of probe – sample separation via operation of the driving means (16, 22) in response to a variation in an average value of one of the at least one parameters away from a predetermined set value;

   characterised in that, the microscope (10) is arranged, in operation, to carry out a scan of the sample surface wherein scan area is covered by an arrangement of scan lines, each scan line being collected by oscillating the probe at or near its resonant frequency such that oscillation amplitude determines scan line length and their arrangement is provided by operation of the driving means (16, 22).

2. A microscope according to claim 1 characterised in that the probe is metallic and the parameter indicative of the interaction force is

capacitance of an interface between probe and sample.

3. A microscope according to claim 1 characterised in that the parameter indicative of the interaction force is oscillation amplitude.

4. A microscope according to claim 2 characterised in that a second parameter indicative of the interaction force, and the one on which the feedback mechanism (26) operates, is oscillation amplitude.

5. A microscope according to claim 2 or 4 characterised in that the probe detection mechanism (24) comprises a modulation signal generator (48) arranged to apply a modulating voltage across the interface between probe (20) and sample (12) in order to modulate its characteristics and thereby affect its electrical capacitance, a resonator (42) arranged to set up a resonating electric field in a circuit incorporating the probe (20) and sample (12) and a detector (46) arranged to measure the electric field resonant frequency and thereby to enable variations in the capacitance of the interface to be measured as the modulating voltage is applied.

6. A microscope according to claim 1 characterised in that the probe (20) comprises a cantilever and actuator arranged to drive the cantilever in a "tapping" mode and the parameter indicative of the strength of the interaction force is bending of the cantilever as it taps the sample (12).

7. A microscope according to claim 1 characterised in that the probe (20) is adapted to interact with a magnetic field and the probe detection mechanism (24) is arranged to measure a parameter indicative of the magnetic interaction between the probe (20) and the sample (12).

8. A microscope according to any preceding claim characterised in that the feedback mechanism (26) operates with a time constant which is greater than one cycle of probe oscillation and significantly less than

total time taken to perform a scan.

9. A microscope according to any preceding claim characterised in that the driving means (16, 22) is arranged to provide a relative linear translation of probe (20) and sample (12) in a direction substantially orthogonal to a plane in which the probe is oscillated, thereby defining a substantially rectangular scan area.

10. A microscope according to any one of claims 1 to 8 characterised in that the driving means (16, 22) is arranged to provide a relative rotation of probe (20) and sample (12) about an axis substantially coincident with that about which the probe (20) is oscillated, thereby covering the scan area by a circular arrangement of scan lines.

11. A microscope according to any preceding claim, the microscope being adapted to monitor charge distribution in a semiconductor device.

12. A method of rapidly collecting image data from a scan area of a sample (12) with nanometric features wherein the method comprises the steps of:-

    (a) Moving a probe (20) with tip of sub-nanometric dimensions into close proximity with a sample (12) in order to allow an interaction force to be established between probe (20) and sample (12);

    (b) Oscillating the probe (20) across the surface of the sample (12) at or near its resonant frequency whilst providing a relative motion between the probe (20) and surface such that an arrangement of scan lines, whose length corresponds to oscillation amplitude, covers the scan area;

    (c) Measuring a parameter indicative of the interaction force strength;

(d) Monitoring the parameter measured in step (c) or a second parameter which is also indicative of an interaction force between probe (20) and sample (12) and, if a value of the monitored parameter falls below or rises above a predetermined set value, adjusting probe (20) – sample (12) separation distance in order to drive the value of the monitored parameter back towards the set value; and

(e) Processing measurements taken at step (c) in order to extract information relating to the nanometric structure of the sample.

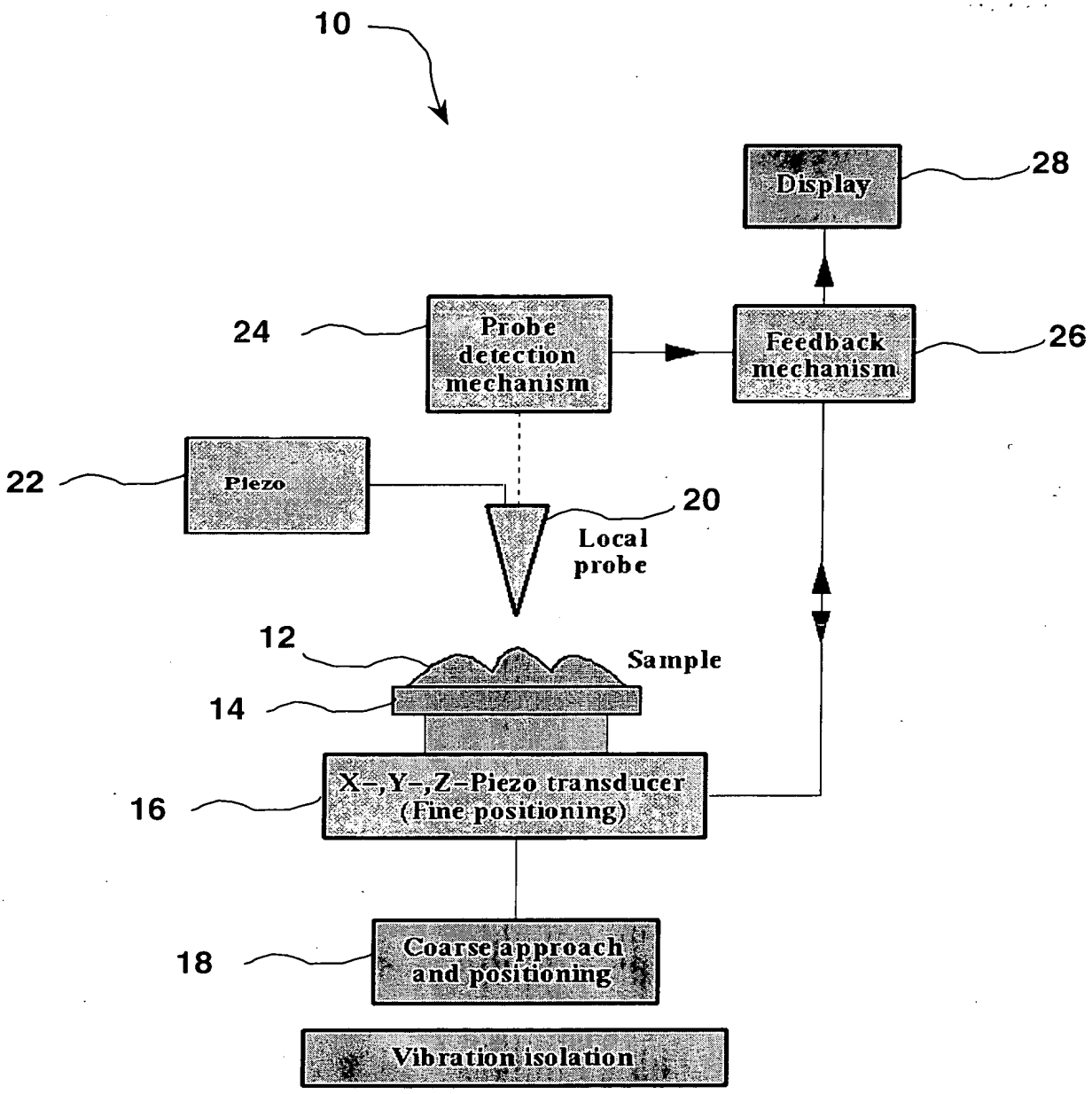
10
Display
28
24
Probe detection mechanism
Feedback mechanism
26
22
Piezo
20
Local probe
12
Sample
14
X–,Y–,Z–Piezo transducer (Fine positioning)
16
Coarse approach and positioning
18
Vibration isolation

Fig 1

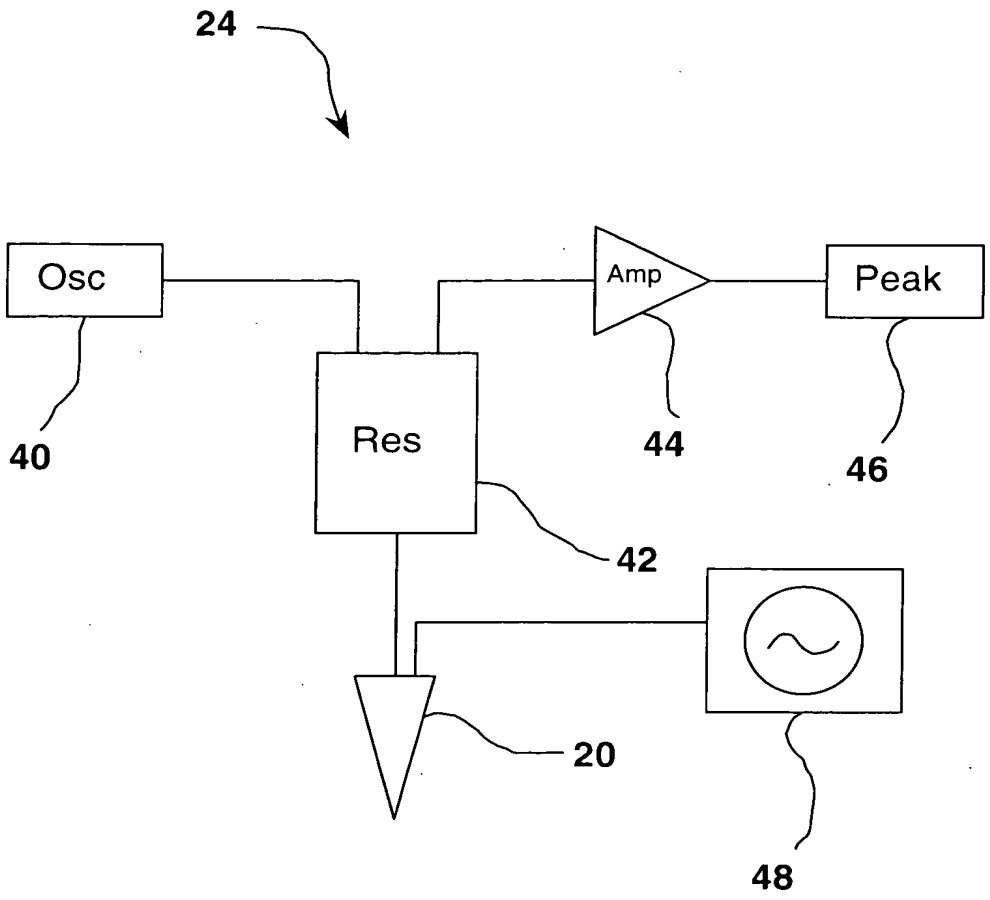

Fig 2